Precision Electroweak Measurements at Energy Frontier

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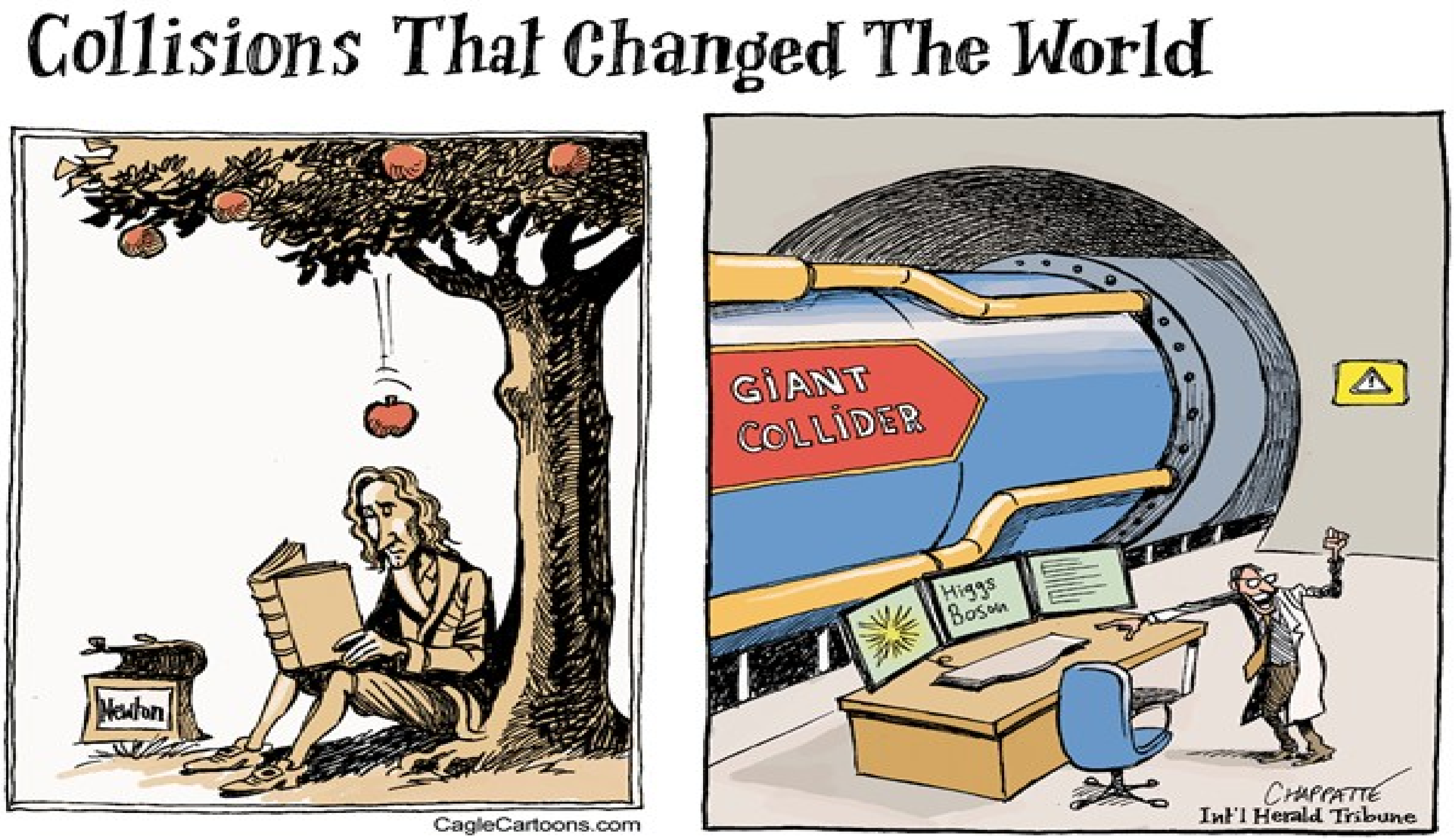

Snowmass Energy Frontier Workshop
Brookhaven National Laboratory,
April 4, 2013

Why are we here?

Why am I here ?

Why am I here ?

spend

Q: Why is it important to you to [redacted] your life measuring the W mass to high precision?

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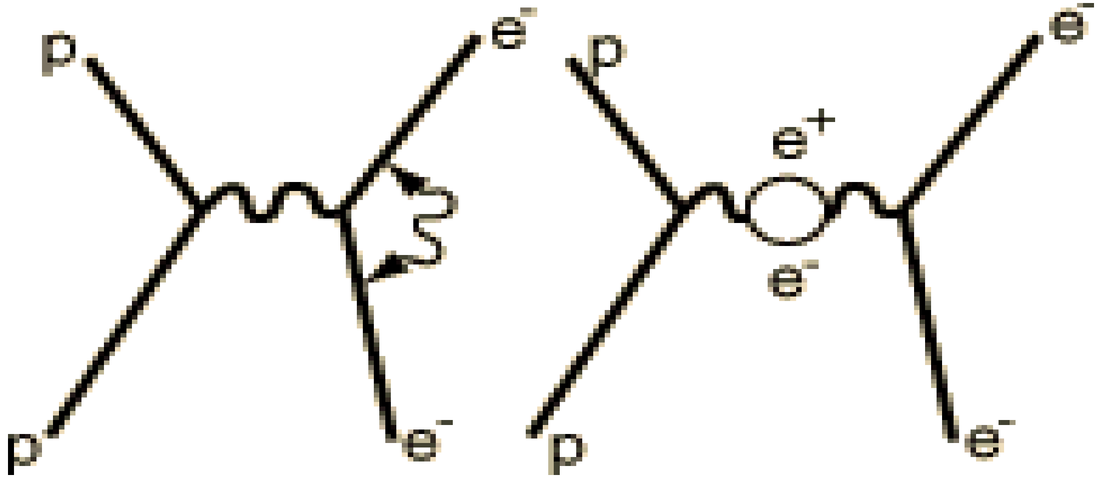
spend

Q: Why is it important to you to [redacted] your life measuring the W mass to high precision?

A: Quantum loop effects are a lot of fun to measure, and I think they will continue to guide us towards the next (BSM) theory

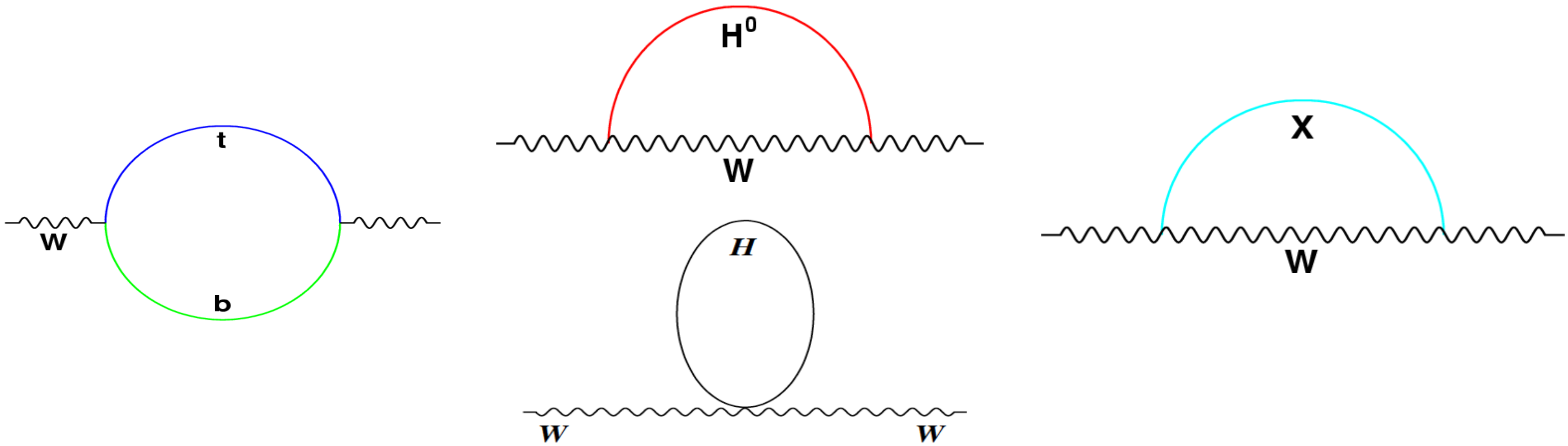
Detecting New Physics through Precision Measurements

- Willis Lamb (Nobel Prize 1955) measured the difference between energies of $^2S_{½}$ and $^2P_{½}$ states of hydrogen atom
  - 4 micro electron volts difference compared to few electron volts binding energy
  - States should be degenerate in energy according to tree-level calculation
- Harbinger of vacuum fluctuations to be calculated by Feynman diagrams containing quantum loops
  - Modern quantum field theory of electrodynamics followed (Nobel Prize 1965 for Schwinger, Feynman, Tomonaga)



Motivation for Precision Measurements

- Radiative corrections due to heavy quark and Higgs loops and exotica

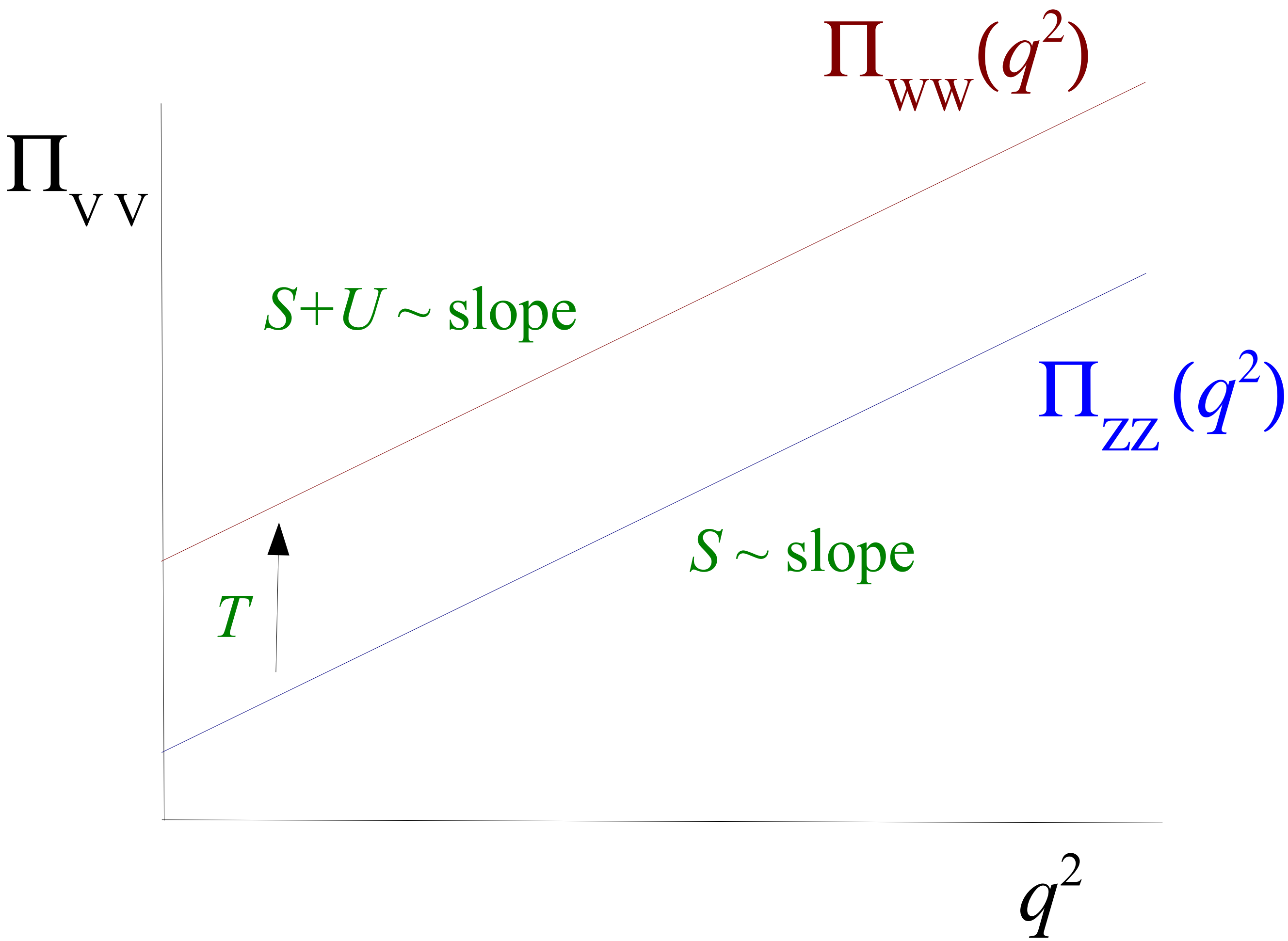


Motivate the introduction of the ρ parameter: $M_W^2 = \rho\,[M_W(\text{tree})]^2$
with the predictions $\Delta\rho = (\rho-1) \sim M_{top}^2$ and $\Delta\rho \sim \ln M_H$

- In conjunction with M_{top}, the W boson mass constrains the mass of the SM Higgs boson, and possibly new particles beyond the standard model

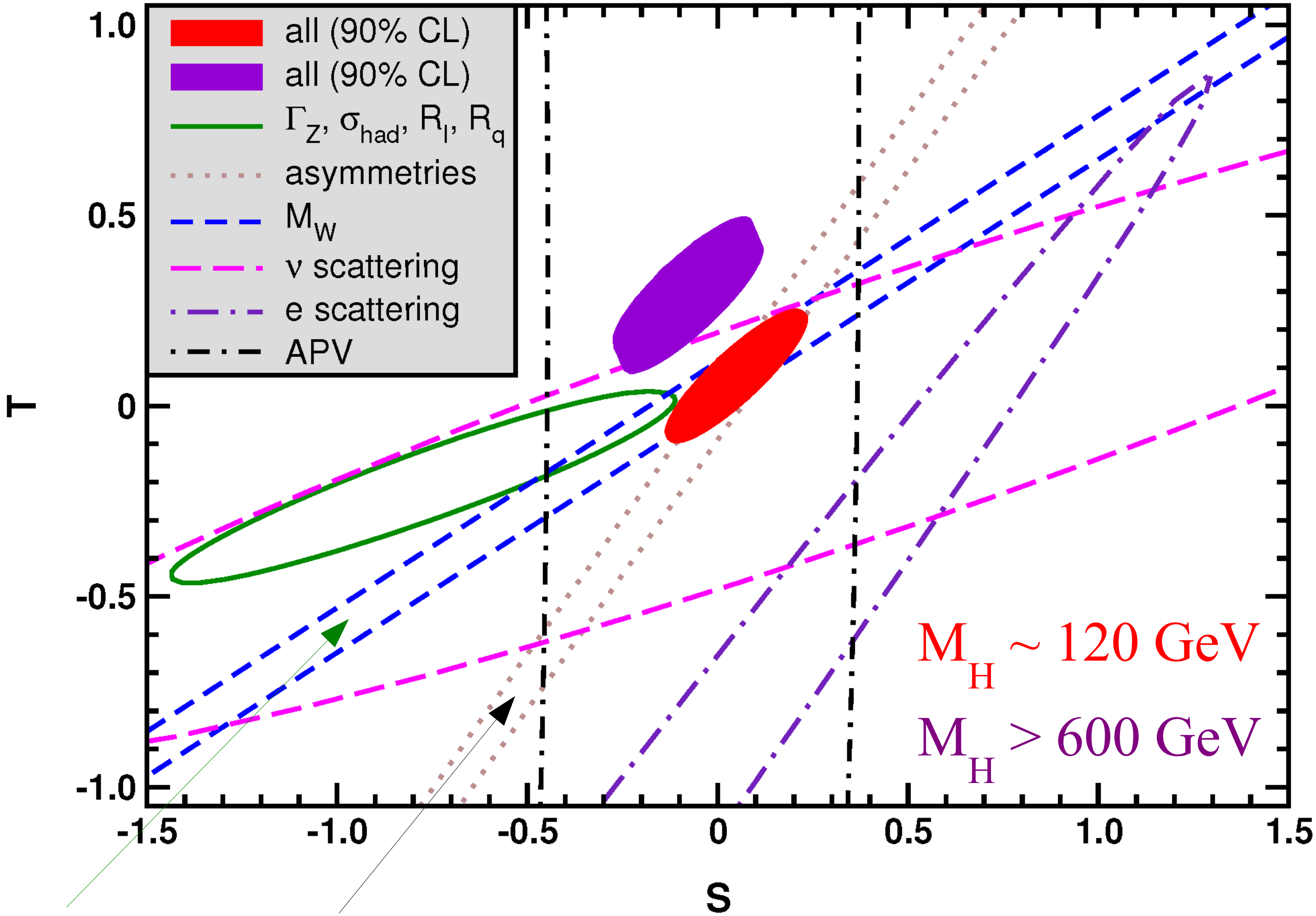
Generic Parameterization

- Generic parameterization of new physics contributing to *W* and *Z* boson self-energies through radiative corrections in propagators
  - *S, T, U* parameters (Peskin & Takeuchi, Marciano & Rosner, Kennedy & Langacker, Kennedy & Lynn)



S, *T* and *U*

- Generic parameterization of new physics contributing to *W* and *Z* boson self-energies: *S*, *T*, *U* parameters (Peskin & Takeuchi)



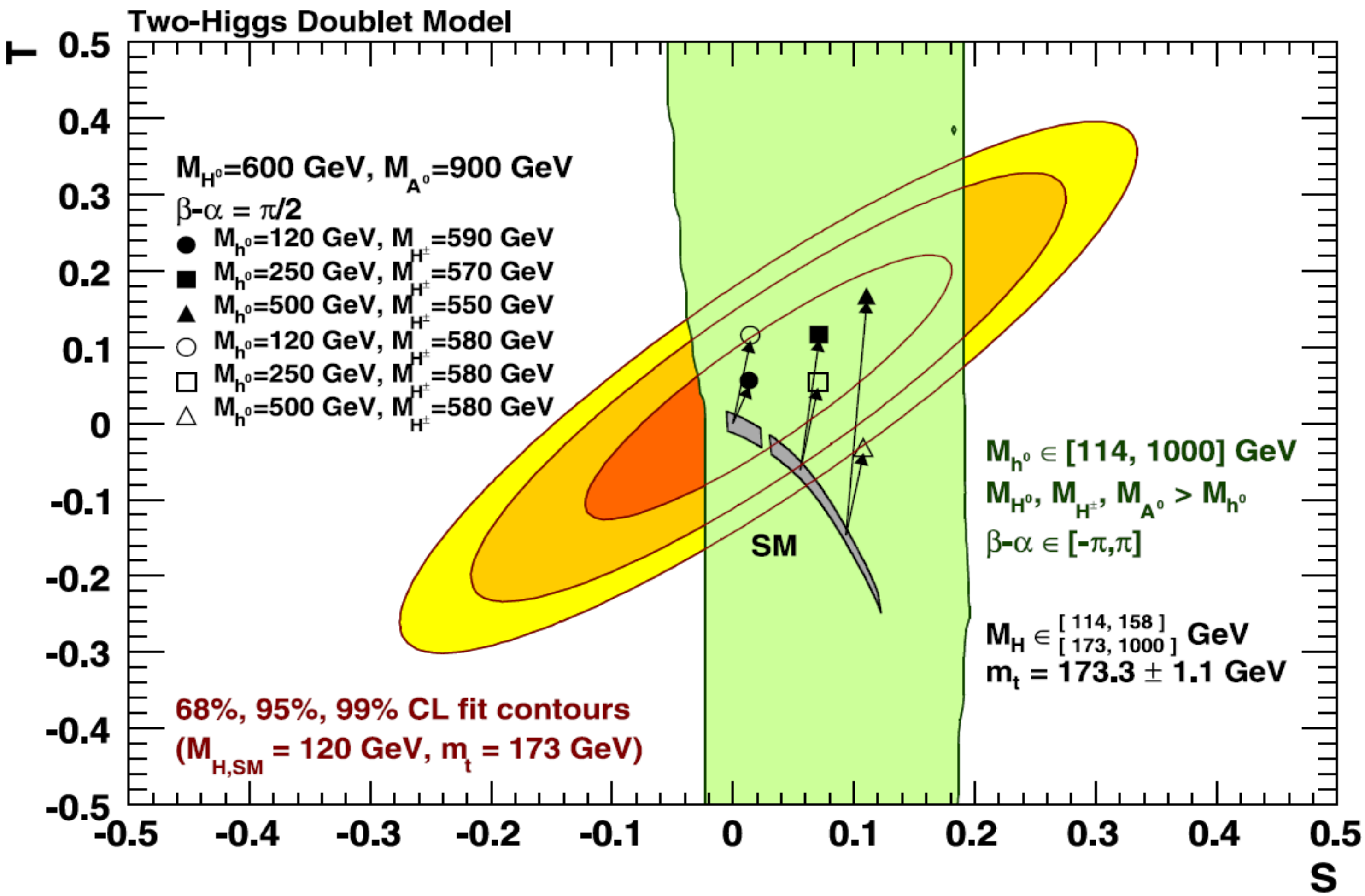
Additionally, M_W is the only measurement which constrains *U*

(from P. Langacker, 2012)

M_W and Asymmetries are the most powerful observables in this parameterization

Extended Higgs Sector

- An example: extending the Higgs sector to two SU(2) doublets (required in SUSY) predicts additional neutral scalar and pseudo-scalar, and charged Higgs bosons

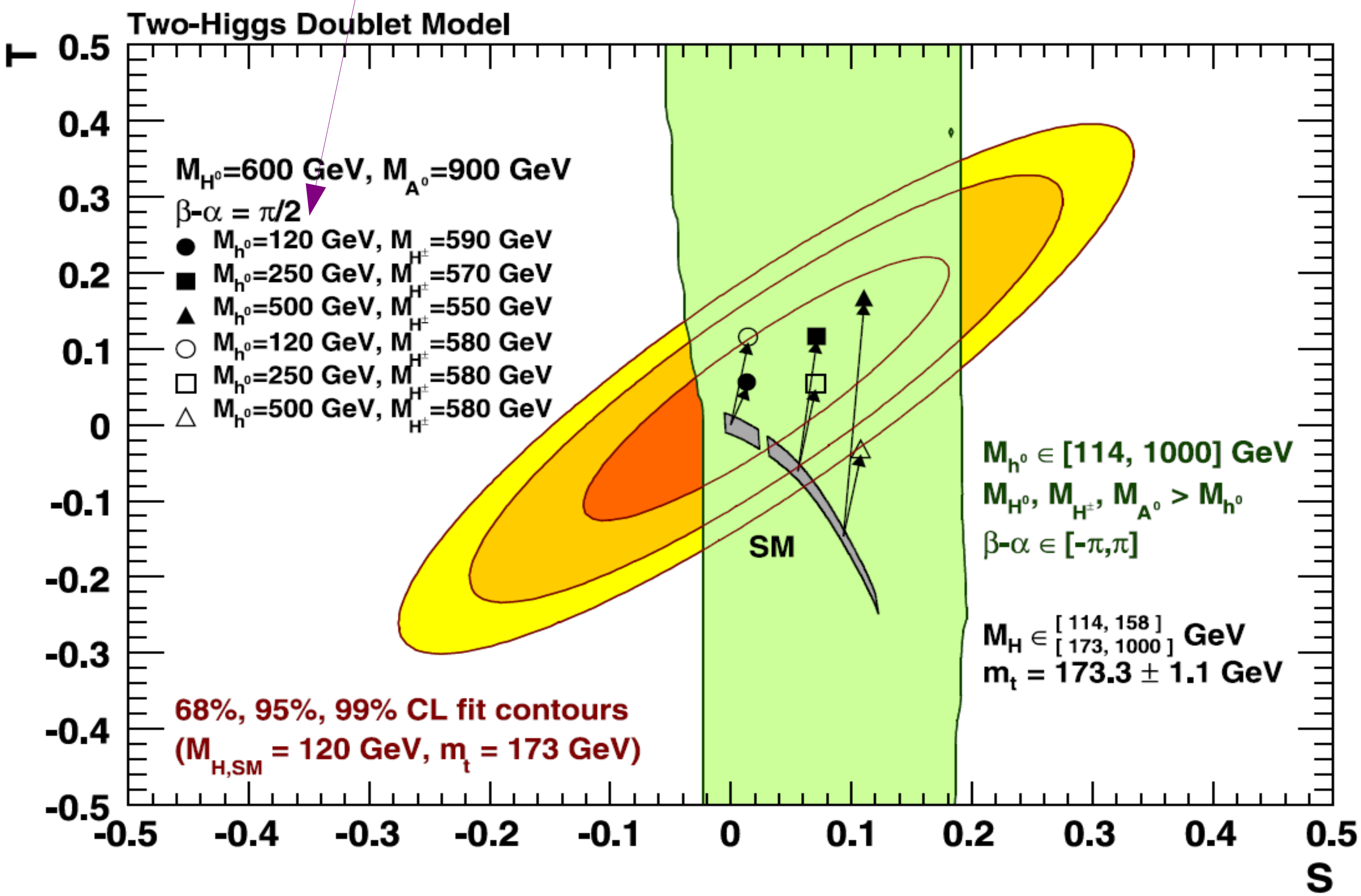


(from M. Baak *et al.* (Gfitter Group) Eur. Phys. J. C (2012) 72:2003)

T parameter responds strongly to 2HDM parameters

Complementarity

- Note complementarity with precision h^0 measurements:
  - for β-α = $\pi/2$, h^0 couplings to *WW* and *ZZ* equal its SM couplings



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T parameter responds strongly to 2HDM parameters

What is M_W sensitive to in MSSM?

- 2HDM embedded in MSSM characterized by $\tan\beta$ and m_A
- At tree level, $m_h \sim m_Z \cos 2\beta$, $m_A \sim (2b/\sin 2\beta)^{1/2}$ with either
  - b not too small (> 20 GeV), or
  - $\tan\beta$ large
    - otherwise m_h and m_A too small
- Using tree-level masses of Higgses, calculate *S, T, U* (Baak *et al.*, EPJC 72, 2003 (2012) and references therein) due to 2HDM
  - For allowable $\tan\beta$ and m_A, *S, T, U* < 1%
- M_W appears insensitive to 2HDM sector of MSSM

What is M_W sensitive to in MSSM?

- Caveat: tree-level masses of additional Higgses tend to become degenerate in MSSM
- Loop corrections to these masses may break degeneracy and induce non-zero *S, T, U*
  - If $m_{H+} - m_A \sim 70$ GeV, $T \sim 15\%$
  - With $\delta M_W \sim 7$ MeV, can be 6σ effect
  - LHC, ILC should aim for $\delta M_W \sim 5$ MeV each

What is M_W sensitive to in MSSM? Other Models?

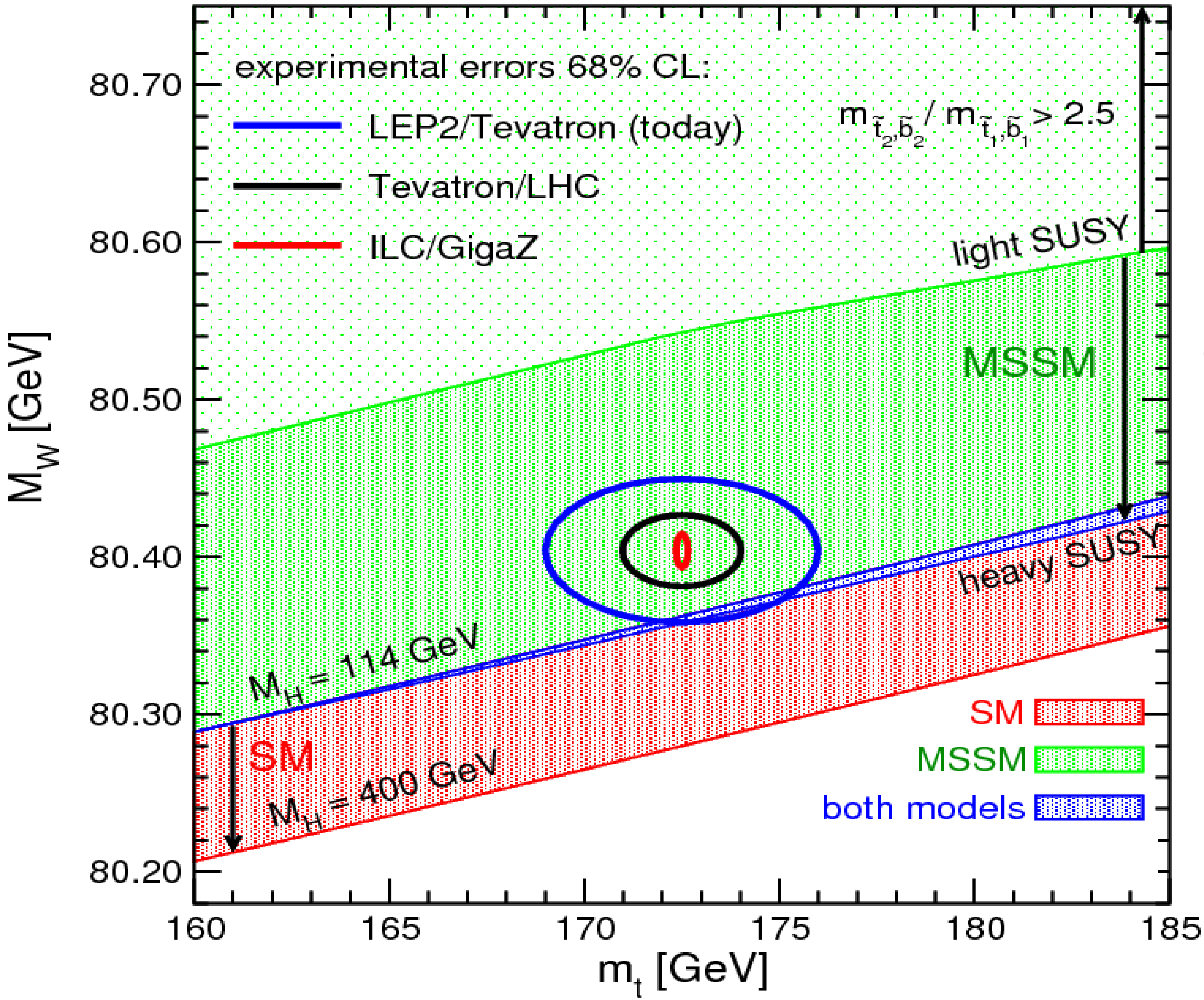
- We should find out – M_W provides a window to what aspect of new physics ?

- Could provide an answer to the "challenge" from Chip and Michael:
  - If $M_W = 80420 \pm 7$ MeV, what would we do?
  - What would we have learnt?

- We need to distill down the loop effects in MSSM to the dominant ones

- Can yield a crisp answer for funding agencies, Congress and perhaps even the taxpayer
  - We should not underestimate the taxpayer's ability to appreciate deep physics if informed in crisp and simple way

M_W *vs* M_{top}



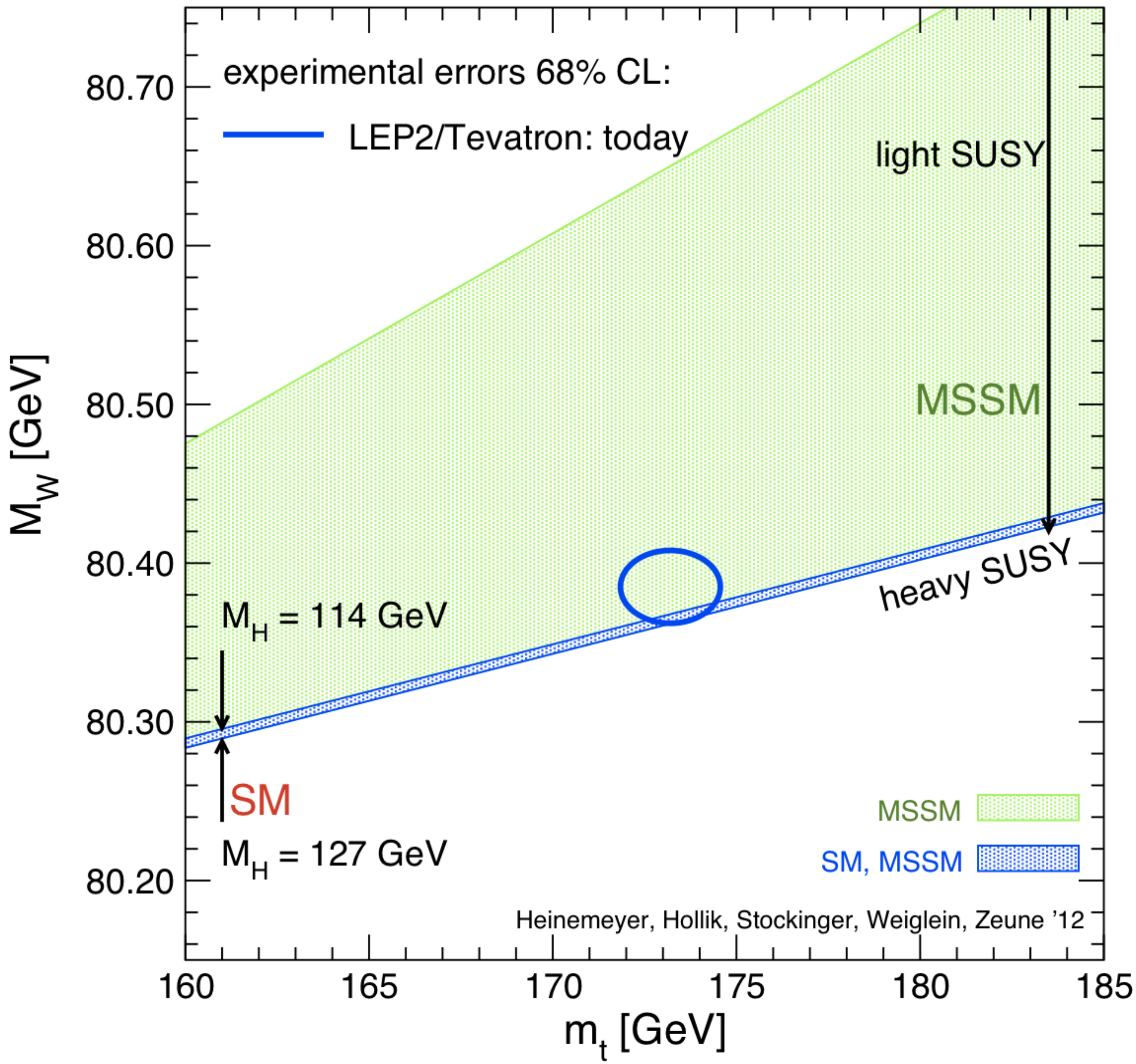
(Heinemeyer *et al.*)

Mass splitting between stops and/or sbottoms induces large contribution to M_W

What is M_W sensitive to in MSSM?

- Expect large mass splitting between stop states
  - large m_{top} expected to induce large mixing
- Large mass splitting can make at least one stop light
- We should isolate and highlight the quantitative sensitivity of stop mass splitting on M_W
- In conjunction with direct stop search sensitivity, can make a crisp (compelling?) paragraph in Energy Frontier executive summary

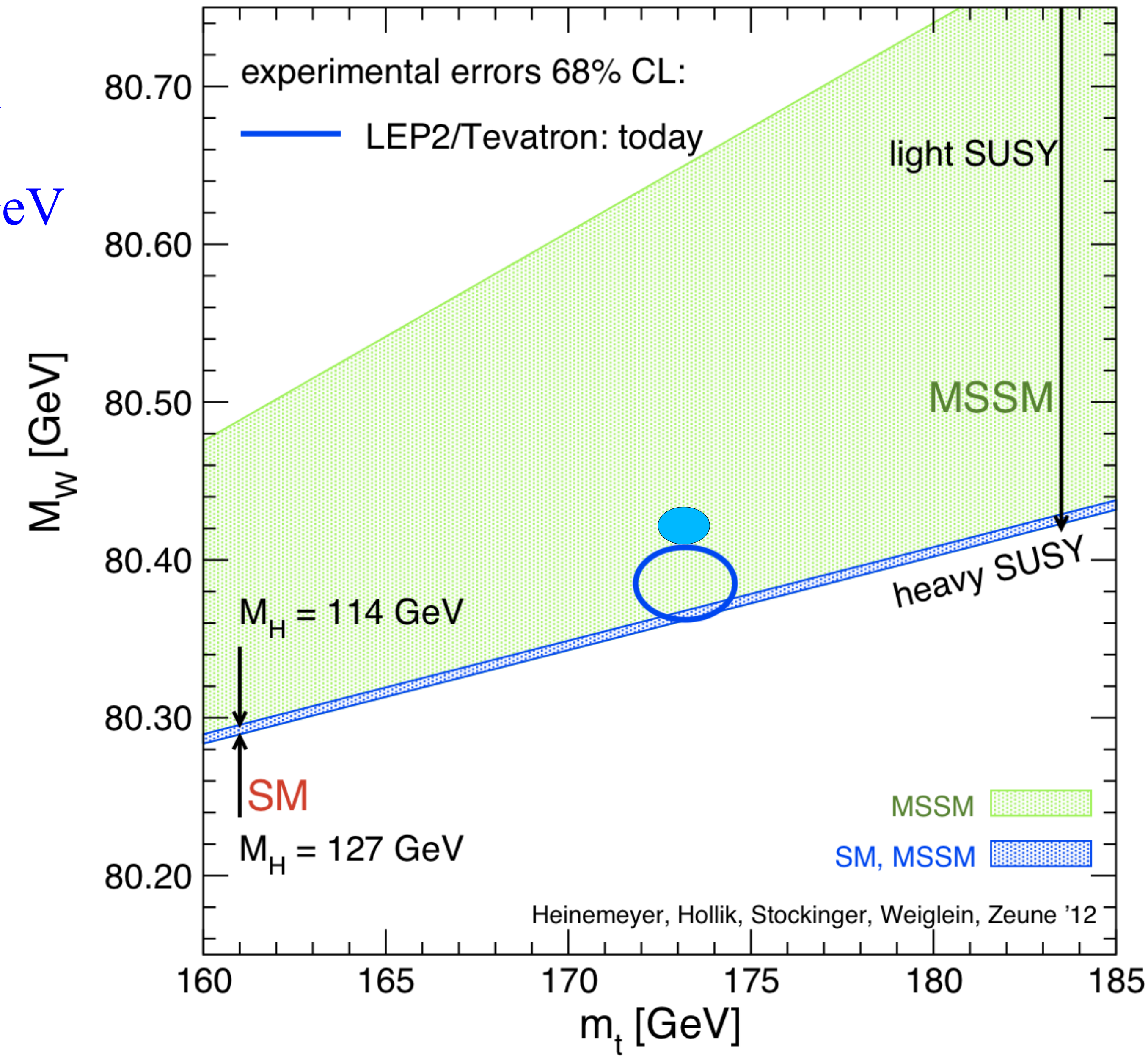
2012 Status of M_W *vs* M_{top}



Improved M_W *vs* M_{top} (half the current uncertainties)

$\delta M_W \sim 7$ MeV

$\delta m_{top} \sim 0.5$ GeV



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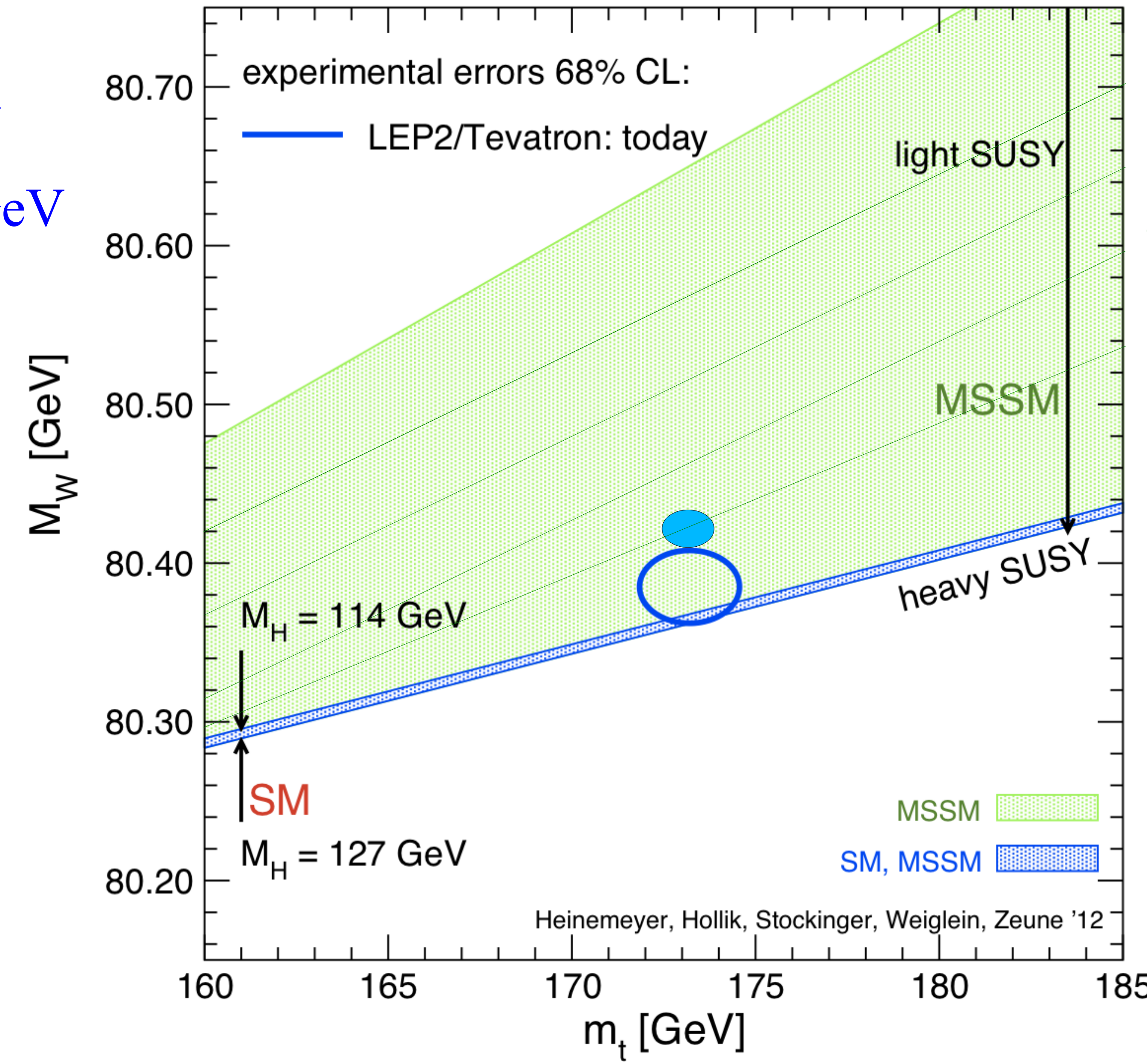

Stop splitting?

Other Comments

- MSSM is nice (due to "minimal") but also fine-tuned at ~1% now?

- Is it time to move to NMSSM, and/or something else?
  - NMSSM answers the question – how can μ term (which is SUSY-invariant) be close to Electroweak scale ?

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- My recommendation: find a way to connect Energy Frontier physics with Dark Matter
  - Lot of circumstantial evidence that Dark Matter ~ TeV-scale WIMP
  - Dark matter *PROVES* that BSM physics exists
  - Taxpayer finds Dark Matter fascinating (perhaps even more than Higgs)
  - Its good to be in the intersection of Frontiers Venn diagram

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  - e.g. QCD quantum loops => running of α_s => mass scale (Λ_{QCD}) from scale-invariant Lagrangian => proton mass

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  - e.g. QCD quantum loops => running of α_s => mass scale (Λ_{QCD}) from scale-invariant Lagrangian => proton mass

- Loops => fine-tuning problem of SM should be taken seriously and should continue to guide our thinking
  - What keeps the Higgs boson's mass low?
  - May also solve half of the cosmological constant problem (on a log scale)

- Fine-tuning + Dark Matter = a physics case for Energy Frontier